| Research Area 4-1. Improved processes for treating impaired waters for energy use. | |
|---|---|
| Statement of Need | Reduce energy requirements for innovative treatment processes (e.g., membranes) |
| Research Objective | Develop the next-generation R) and microfiltration/ultrafiltration (MF/UF) membranes. |
| Impact/Benefits | 1. Increase MF/UF flux by using hydrophilic (more wettable) membranes<br>2. Reduce RO feed pressure by using better polymers<br>3. Reduced energy requirements for innovative process trains |
| Priority | High priority—Existing membrane energy use is being optimized now. |
| Summary Scope of Work | 1. Identify better MF/UF/RO membranes that meet the needs<br>2. Conduct applied research (bench testing/pilot testing)<br>3. Documentation/report and development program |
| Technical Approach | 1. Test more negatively charged MF/UF membranes (organic removal)<br>2. Test RO membranes with higher hydraulic conductivity<br>3. Specify energy savings compared to current membranes |
| Lead Investigators (academia, natl. lab, industry, international, partnership) | Applied research departments—water agencies experienced with membranes/recycled water (e.g. Orange County Water District) |
| Potential Collaborative Govt. Agencies | AwwaRF |
| Leverage Opportunities with Existing Programs | Build on similar existing programs (e.g., OCWD, AwwaRF, DOE) |
| Constraints/Challenges (Policy, regulatory, technical, sequencing?) | None known |
| Estimated Cost | $300-$400k |
| Execution Horizon (early, mid, late) | Early (complete applied research within 5 years for immediate implementation) |
| Schedule/Duration | Start in FY07 or FY08. Approximate 2 year duration. |
| Level of Development/Level of Maturity at completion | Based on previous research on membranes for reuse, the completed work will lead to immediate implementation (full scale demonstration and design) in the energy and water industries. |
| Additional comments | |

| Research Area 4-1a. Improved processes for treating impaired waters for energy use. | |
|---|---|
| Statement of Need | Treat produced and impaired water for energy facilities use. |
| Research Objective | Develop treatment technologies and processes to remove constituents of concern including salts, heavy metals, corrosives, fouling materials (including inorganic, organic and biological) and scalants from produced and impaired water for energy use. Reduce energy requirements for treatment processes. |
| Impact/Benefits | High-grade use of lower quality water for energy production use. |
| Priority | High priority for water producers and for future plants development. |
| Summary Scope of Work | Identify existing appropriate technologies. Improve / optimize identified technologies. Pilot test identified technologies to specified applications. Transfer information. |
| Technical Approach | Literature research of uses and technologies. Bench-scale testing. Pilot-scale design and testing of technologies to specified applications. Transfer technologies. |
| Lead Investigators (academia, natl. lab, industry, international, partnership) | Research by national labs and academia, development in cooperation with vendors and en-users, bench-scale testing by labs, pilot testing in cooperation with vendors and end-users. |
| Potential Collaborative Govt. Agencies | AwwaRF |
| Leverage Opportunities with Existing Programs | Build on similar existing programs (e.g., OCWD, AwwaRF, DOE) |
| Constraints/Challenges (Policy, regulatory, technical, sequencing?) | Variable source water qualities. Validate water suitability to the energy producer. |
| Estimated Cost | $2 million to $5 million. |
| Execution Horizon (early, mid, late) | Early (complete applied research within 5 years for immediate implementation). |
| Schedule/Duration | Five to ten years. |
| Level of Development/Level of Maturity at completion | Ready for industry application upon completion of project. |
| Additional comments | |

| **Research Area 4-2. Review, prove in-field novel treatment techs developed in past DOE work; create water for beneficial use.** | |
|---|---|
| Statement of Need | Review, prove-in previously developed novel treatment technologies (doesn't have to be just DOE work). |
| Research Objective | • In-field application of different lab-demonstrated technologies for given applications at different scales<br>  ○ Identify scale-up issues in going from lab testing to in-field testing; determine limit of scalability of each technology<br>• Predictive modeling<br>• Comparison of technologies<br>  ○ Safe<br>  ○ Prefer inexpensive<br>  ○ Robustness, lifetime<br>  ○ Performance predictability<br>  ○ Integration with existing infrastructure & data processing systems<br>  ○ Prefer technologies that produce no/minimal waste<br>  ○ Prefer portability |
| Impact/Benefits | • Cost, energy, & water savings – inform optimal ways to conserve, use, & reuse water<br>• Inform policy & legal decisions<br>• Rapid & accurate feedback for critical field application decisions |
| Priority | High |
| Summary Scope of Work | Need to identify:<br>• What are the most promising lab-demonstrated technologies?<br>• Potential users & potential in-field test sites<br>• Mechanism for bringing together lab-demonstrated technologies with users<br>Create a broadly accessible database showing how each technology scores according to different parameters (see research objectives)<br>Provide opportunities for technology design improvement & optimization |
| Technical Approach | Starting from lab-demonstrated technologies:<br>• Understand user's needs<br>• Establish technology performance standards in collaboration with user<br>• Predictive modeling for scale-up<br>• Screen and tune materials & processes for scalability<br>• Equipment for monitoring of parameters/frequency/accuracy of technologies in in-field testing<br>• Intermediate levels of scale-up testing in laboratory to support in-field scale-up<br>• Iterate selection, testing, & revision of processes & materials until performance standards met |
| Lead Investigators<br>(academia, natl. lab, industry, international, partnership) | Industry and national laboratories<br>End user should be lead |
| Potential Collaborative Govt. Agencies | DOE, EPA, Dept. of Ag., DOI, state & local funding agencies, Awwa, EPRI |
| Leverage Opportunities with Existing Programs | DOE (EERE, Fossil Energy, Nuclear Energy), AwwaRF, EPRI, cost sharing with end user (e.g., industry) |
| Constraints/Challenges<br>(Policy, regulatory, technical, sequencing?) | Economics: Cost<br>Technological: Safe, rapid, no/little waste production, integration into existing infrastructure, compatible with local environmental conditions<br>Regulatory: compatible with existing regulations |

| | |
|---|---|
| | Psychological barrier: Is the public ready to accept, for example, drinking water or irrigation water produced from impaired water? |
| Estimated Cost | $20M/yr for 5 yrs |
| Execution Horizon<br>(early, mid, late) | Mid (immediately after lab demonstration completed) |
| Schedule/Duration | For specific applications, 1 – 2 years after lab demo completed<br>~5 yrs for whole research area |
| Level of Development/Level of Maturity at completion | Deployable technology |
| Additional comments | Discussion:<br>- Expand "Produced Water" to "Produced & Impaired Water"<br>- Minimizing energy use in creating & using produced & impaired water – is this a separate research area? This includes applications beyond oil & gas, conveyance, re-use & conservation in industrial applications. Ultimately decided it include in research area 4-4.<br>- Include disinfection as a concern in research area 4-3. What are alternatives to chlorination & oxidizing biocides?<br>- Need to determine water quality & quantity standards needed for different applications<br>- Water needs are frequently localized; there are institutional issues<br>- Technology is the not the problem – permitting is<br>- We decided that research area 4-6 was more of a standards issue & not a technology issue. Recommend re-classifying it to group 1. We did not work on 4-6. |

| **Research Area 4-3. Develop/optimize scalable treatment plants for produced or impaired water to meet specific standards for the intended uses.** | |
|---|---|
| Statement of Need | Develop/optimize treatment plants for produced or impaired water that match the intended use. |
| Research Objective | Develop/optimize scalable treatment plants for produced or impaired water to meet specific standards for the intended uses including livestock / wildlife consumption, irrigation, power plant supply, industrial and domestic uses.<br><br>Reduce power requirements and optimize power sources to these plants. |
| Impact/Benefits | Provide water for designated needs. Reduce the consumption of water treated for higher uses. |
| Priority | High priority in the western U.S. because of continuing draught conditions and population growth. |
| Summary Scope of Work | Identify all possible uses. Identify existing appropriate technologies. Match appropriate technologies to the needs. Improve / optimize identified technologies. Pilot test identified technologies to specified applications. Transfer information to industries that can use it. |
| Technical Approach | Literature research of uses and technologies. Laboratory-scale testing. Pilot-scale design and testing of technologies to specified applications. Transfer technologies. |
| Lead Investigators (academia, natl. lab, industry, international, partnership) | Research by national labs and academia, development in cooperation with vendors and en-users, bench-scale testing by labs, pilot testing in cooperation with vendors and end-users. |
| Potential Collaborative Govt. Agencies | State agencies including DEQ's and SEO's. |
| Leverage Opportunities with Existing Programs | WERK, AWWA |
| Constraints/Challenges (Policy, regulatory, technical, sequencing?) | Funding, variable state-to-state and changing regulatory targets, effective partnering, satisfying end-users' needs within necessary time limits. |
| Estimated Cost | $2 million to $5 million |
| Execution Horizon (early, mid, late) | Start now and finish within two years (early) |
| Schedule/Duration | Two years. |
| Level of Development/Level of Maturity at completion | Should be ready for implementation. |
| Additional comments | |

| **Research Area 4.4. Pilot tests to evaluate performance of new materials for treating impaired water.** | |
|---|---|
| Statement of Need | Need a systematic test-bed for evaluating new materials/processes for site-specific, stream specific applications. |
| Research Objective | Evaluate efficacy of laboratory demonstrated materials/processes at pilot (demonstration scale) field evaluation (scale-up almost always presents challenges to new technology). |
| Impact/Benefits | More appropriate water quality for each specific end use (i.e. eliminates "over-treatment"). Better, more energy efficient treatment technologies. |
| Priority | High (pilot scale studies are a critical cog in the deployment of any technology) |
| Summary Scope of Work | Demonstrating new technologies, specifically through competitive solicitation, evaluated in terms of impact, cost, universality, etc. This will require a mobile platform (e.g. semi- trailer) that can be readily reconfigured for specific stream needs. |
| Technical Approach | This research area has several components:<br>Chemically selective sorbent materials (especially nanomaterials)<br>Chemically selective membranes ("smart membranes"), especially those<br>Containing self-cleaning surfaces<br>Biomimetic separation processes (need to be more robust)<br>Energy efficient chemical processing (e.g. redox chemistry) |
| Lead Investigators (academia, natl. lab, industry, international, partnership) | Academia, national laboratories and industry. This effort will have a significant research component (academia and national laboratories), a manufacturing component (industry) and a deployment component (industry). |
| Potential Collaborative Govt. Agencies | DOE, DoD, EPA, NIH, state governments, water districts, SBIR |
| Leverage Opportunities with Existing Programs | AwwaRF, NSF National technology Initiative, WateReuse Foundation, Western Energy Research, US Bureau of Reclamation |
| Constraints/Challenges (Policy, regulatory, technical, sequencing?) | Nanomaterial synthesis at the industrial scale is currently limited (but growing). |
| Estimated Cost | Ca. $5M |
| Execution Horizon (early, mid, late) | Variable – many different components at different levels of maturity |
| Schedule/Duration | 2-3 years |
| Level of Development/Level of Maturity at completion | Variable – many different components at different levels of maturity |
| Additional comments | |

| **Research Area 4-5. Mobile, scalable treatment systems.** | |
|---|---|
| Statement of Need | Treat, manage and/or discharge a variety of water types and volumes at the site where generated. These systems must be mobile, scalable, economic to operate with remote monitoring and callout. |
| Research Objective | Mobile, scalable treatment systems that have low operating costs, can operate in a variety conditions and climates and that can process variable and low water feed rates. Optimize gathering from multiple water sources / wells. Address systems economies of scale. These must operational with remote monitoring and callout. |
| Impact/Benefits | Reduces hauling and other water management costs while providing water for local uses. Allows for remote exploration & development. Minimizes environmental impacts. |
| Priority | Medium priority, but results could be used in current applications. |
| Summary Scope of Work | Identify existing scalable appropriate technologies. Improve/optimize identified technologies. Pilot test identified technologies to specified application. Transfer information to industry. |
| Technical Approach | Literature research of technologies. Bench-scale testing. Pilot-scale design and testing of technologies. Transfer technologies. |
| Lead Investigators (academia, natl. lab, industry, international, partnership) | Research by national laboratories and academia, development in cooperation with vendors and end-users, bench-scale testing by labs, pilot testing in cooperation with vendors and end-users. |
| Potential Collaborative Govt. Agencies | Local, state and federal agencies. |
| Leverage Opportunities with Existing Programs | WERK, USDA and WRRI affiliated with state ag schools. |
| Constraints/Challenges (Policy, regulatory, technical, sequencing?) | Highly variable quantities, qualities and locations of water sources. Funding, variable state-to-state and changing regulatory targets, effective partnering. |
| Estimated Cost | $2 million to $5 million |
| Execution Horizon (early, mid, late) | Early |
| Schedule/Duration | Two years. |
| Level of Development/Level of Maturity at completion | Ready for industry application upon completion of project. |
| Additional comments | |

| Research Area 4-7. Identify/incentivize/applying beneficial use applications for produced waters in energy sector applications. | |
|---|---|
| Statement of Need | A need to identify/incentivize/applying non-disposal uses of produced and other unconventional waters |
| Research Objective | Identify and apply/implement alternative applications for produced and other energy-related unconventional water resources (hybrid cooling systems, oil shale use, etc.).<br><br>Establish water quality requirements for a variety of proposed reuse applications |
| Impact/Benefits | Eliminates disposal costs and regulatory issues associated with discharge<br>Conserves water resources<br>Creates new water source |
| Priority | High (to come up with incentives) |
| Summary Scope of Work | Perform feasibility study, considering applications in wide context (transportation, regulations, liability, economics, cultural, environmental)<br>Validate existing identified applications |
| Technical Approach | NA/TBD |
| Lead Investigators (academia, natl. lab, industry, international, partnership) | DOE to lead<br>Third party to run (funded by DOE, watched by industry, collaborative (BLM, DEQ) academics (subconsultants) |
| Potential Collaborative Government Agencies | BLM, DEQ |
| Leverage Opportunities with Existing Program | Identify previous studies that have been performed |
| Constraints/Challenges (Policy, regulatory, technical, sequencing?) | Transportation (economics)<br>Regulation (reclassify as resource and not waste product)<br>Cultural |
| Estimated Cost | Up to $1 M |
| Execution Horizon (early, mid, late) | Early (0 - 5 yrs) |
| Schedule/Duration | 2 – 5 yrs |
| Level of Development/ Level of Maturity at completion | Mature |

| Research Area 4-8. Create specialized centralized sharable database on produced water quantities, quality, frequency, and locations. | |
|---|---|
| Statement of Need | The current quantity, quality, frequency, and locations of produced waters available for use are largely unknown outside of the producers. Such information must be collected so that it is usable by energy and water planners. |
| Research Objective | Create specialized, centralized, sharable database on produced water quantities, quality, frequency, and locations |
| Impact/Benefits | Information will enable development of new produced water projects |
| Priority | Medium |
| Summary Scope of Work | Develop interactive database |
| Technical Approach | Develop database<br>Literature search<br>Industry survey |
| Lead Investigators (academia, natl. lab, industry, international, partnership) | DOE funded (third party to conduct) |
| Potential Collaborative Government Agencies | BLM, DEQ, Oil and Gas Commissions, State Gas Engineers |
| Leverage Opportunities with Existing Programs | Previous API studies |
| Constraints/Challenges (Policy, regulatory, technical, sequencing?) | Proprietary data<br>Freedom of Information Act (FOIA)<br>Data inconsistency (quality) |
| Estimated Cost | No more than $0.5 M |
| Execution Horizon (early, mid, late) | Early |
| Schedule/Duration | 1 yr |
| Level of Development/ Level of Maturity at completion | Mature, never fully developed |
| Additional Comments | |

| **Research Area 4-11. Develop pilot efforts to assess impacts of use of produced water for energy development and other uses (collect cost and performance data).** | |
|---|---|
| Statement of Need | Productive use of produced waters will be facilitated by rigorous cost and performance data. |
| Research Objective | Develop pilot efforts to assess impacts of use of produced water for energy development and other uses (collect cost and performance data). |
| Impact/Benefits | Provide feasibility data and guidance for industry<br>Ease the way for industries to use produced waters in their operations<br>Eliminate discharge issues and conserve water resources |
| Priority | High (most important) |
| Summary Scope of Work | Collect appropriate performance and cost data at a pilot site performing tests with various treatment technologies with produced water, with input from appropriate stakeholders |
| Technical Approach | Identify applications<br>Identify previous studies (industry survey)<br>Generate cost and performance data<br>Perform surface-spreading application to demonstrate to BLM the environmental application of treated produced water |
| Lead Investigators (academia, natl. lab, industry, international, partnership) | DOE to fund (third party to perform)<br>Water center associated with university |
| Potential Collaborative Government Agencies | BLM, State and local DEQ, USGS, soil conservation districts, water districts, State Engineers, NGOs |
| Leverage Opportunities with Existing Programs | Work with existing data and industries<br>Industry groups, including AwwaRF, WateReuse Foundation |
| Constraints/Challenges (Policy, regulatory, technical, sequencing?) | Institutional<br>Regulatory<br>Economic (new infrastructure, new treatment) |
| Estimated Cost | $5 - $10 M |
| Execution Horizon (early, mid, late) | Early |
| Schedule/Duration | 5 to 10 yrs |
| Level of Development/ Level of Maturity at completion | Mature but not complete |
| Additional Comments | |

| Research Area 4-12a. Clarify regulatory Infrastructure for injection of treatment wastes. | |
|---|---|
| Statement of Need | Existing regulatory infrastructure that would apply to injection of wastes from treatment of non-traditional waster resources is unclear. This lack of clarity could lead to excessive or unnecessary requirements that add costs without commensurate environmental benefits. |
| Research Objective | This is not a research activity in the strict sense. This effort would require a review of existing regulations and identification of the necessary amendments to regulations (and possibly enabling legislation) leading to reasonable regulations applicable to the injection of wastes generated when treating non-traditional water resources. |
| Impact/Benefits | Allow disposal of wastes in an environmentally sound manner without excessive regulatory requirements. Controlling these waste disposal costs will improve the economic viability of utilizing non-traditional water resources. Where non traditional water resources are used in municipal applications, the resulting cost savings can be translated to saving to taxpayers. |
| Priority | High. The current lack of clarity in how to handle these wastes are inhibiting the degree to which use of these resources are being considered. |
| Summary Scope of Work | Identify regulatory constraints, primarily in regulations issued under authority of the Safe Drinking Water Act and equivalent state level legislation. Develop necessary amendments to regulations (and legislation if needed) and promulgate those amendments. |
| Technical Approach | Perform regulatory gaps analysis. Demonstrate similarities of the treatment wastes to other waste streams (i.e. treatment wastes are characteristically very similar to produced water - saline, high TDS, organics). Draft regulatory amendments to federal regulations that will serve as the template for state regulations and promulgate these amendments.<br><br>A key deliverable of this effort would be to develop a risk based approach to determining which Class of the Underground Injection Control program would apply for a given waste. The risk based process would consider the chemical and physical characteristics of the waste water, exposure pathways and duration, geological considerations. Ideally, the risk assessment would be performed on a case specific basis, or possibly collectively where parameters are sufficiently similar. |
| Lead Investigators<br>(academia, natl. lab, industry, international, partnership) | Industry, GWPC, AWWA, DOE, USGS, BLM, EPA and state agencies. |
| Potential Collaborative Govt. Agencies | A high degree of collaboration between EPA and state environmental and resource agencies is essential. |
| Leverage Opportunities with Existing Programs | There are other issues that may help drive this effort, i.e. the need for similar regulatory amendments to accommodate $CO_2$ injection for carbon capture and sequestration purposes. Ideally, the risk based approach suggested above would be equally applicable to $CO_2$ injection as it would be for waste water disposal. |
| Constraints/Challenges<br>(Policy, regulatory, technical, sequencing?) | This is primarily a policy and regulatory issue. Currently, treatment wastes from non traditional waters (i.e. reject water from RO based processes is the waste of highest interest) are not clearly addressed under the SDWA. The most likely interpretation is that currently these wastes would have to be injected in a Class 1 industrial waste well, despite the fact that characteristically, this waste water is almost identical to many produced waters, which are injected in Class 2 wells. Costs associated with injection in Class 1 wells is significantly higher that Class 2 wells and is not justified given the similarities in the two waters. |

| | |
|---|---|
| Estimated Cost | $250 - $500k |
| Execution Horizon (early, mid, late) | Early |
| Schedule/Duration | 18-24 months plus time to amend regulations. Longer if legislative action is required. |
| Level of Development/Level of Maturity at completion | Mature |
| Additional comments | |

| Research Area 4-12b. Compilation of water quality criteria for reuse in multiple applications. | |
|---|---|
| Statement of Need | A compilation of recognized physical and chemical characteristics for water uses in a variety of beneficial uses would be a valuable resource. The criteria used in this compilation should be drawn from recognized or accepted sources and based on sound scientific information. Having this information could help inform potential users of non traditional water resources of what they should require to avoid damage to their land or assets. |
| Research Objective | Compile recognized water quality standards for a range of potential end uses for non traditional waste waters. Possible uses that should be covered should include crop and rangeland irrigation (considering soil types and crop types), livestock watering (considering different types of livestock), wildlife/habitat enhancement, and industrial uses. |
| Impact/Benefits | The compilation would be a valuable source of information and allow sound decisions to be made when selecting uses for non traditional water resources. |
| Priority | High. This effort would be based on existing information, no new research would be considered. |
| Summary Scope of Work | Identify available resource materials, organize materials based on possible use categories, and reach consensus on recommendations based on existing weight of evidence. Areas where data is weak or incomplete should be identified as areas that may require additional work later. |
| Technical Approach | This is basically a literature search. |
| Lead Investigators (academia, natl. lab, industry, international, partnership) | |
| Potential Collaborative Govt. Agencies | USDA, NRCS, USFWS, EPA and equivalent state agencies in potentially affected states. |
| Leverage Opportunities with Existing Programs | ? |
| Constraints/Challenges (Policy, regulatory, technical, sequencing?) | None are apparent |
| Estimated Cost | $200 - $400k |
| Execution Horizon (early, mid, late) | Early |
| Schedule/Duration | 18-24 months |
| Level of Development/Level of Maturity at completion | Mid level. Compilation and evaluation process is expected to identify specific water quality parameter whose basis is weaker that is desirable and could require new research. |
| Additional comments | |

| Research Area 4-12c. Refinement of specific water quality criteria for reuse in multiple applications. | |
|---|---|
| Statement of Need | A compilation of recognized physical and chemical characteristics for water uses in a variety of beneficial uses (Research Area 4-12b) is expected to identify specific criteria that will require additional research. The purpose of this need is to perform the additional research necessary to better quantify the criteria that are appropriate for those parameters. |
| Research Objective | Refine the data and improve the scientific basis for parameter specific water quality standard recommendations. |
| Impact/Benefits | This will strengthen the scientific and business case supporting the recommended criteria and lead to more rapid and broader acceptance of these criteria. |
| Priority | Medium. Originally offered values will have some level of justification. The intent of this effort is to strengthen the scientific basis for the use criteria. |
| Summary Scope of Work | The project described in Research Area 4-12b will identify the existing state of knowledge and identify parameters for which the data is weak or incomplete.<br><br>Parameters that are identified would be evaluated for the need to do additional work to better quantify the criteria. The level of effort necessary to improve the technical support for any given parameter may be significant and should be evaluated on a case by case basis. |
| Technical Approach | This is basic research and would most likely require field studies. The scope and nature of these studies would have to be developed on a case by case basis. |
| Lead Investigators<br>(academia, natl. lab, industry, international, partnership) | Academia, others? |
| Potential Collaborative Govt. Agencies | USDA, NRCS, USFWS, EPA and equivalent state agencies in potentially affected states. |
| Leverage Opportunities with Existing Programs | ? |
| Constraints/Challenges<br>(Policy, regulatory, technical, sequencing?) | None are apparent |
| Estimated Cost | $2-$5million |
| Execution Horizon<br>(early, mid, late) | Mid to late |
| Schedule/Duration | 2-10 years |
| Level of Development/Level of Maturity at completion | Would depend on the nature of the research and goals of the effort. |
| Additional comments | |

| Research Area 4-12d. Identification of subsurface zones for non-traditional water injection. | |
|---|---|
| Statement of Need | Energy production at many sites will have a concomitant production of excess non-traditional water that will need to be managed. Subsurface injection (for potential future recovery) will be an important aspect of managing these waters. Methodologies are needed for timely identification of subsurface zones that are compatible for receiving these waters and will inhibit mixing with adjacent aquifers. |
| Research Objective | Develop methodologies to rapidly identify and test subsurface zones for receiving non-traditional waters. |
| Impact/Benefits | Onsite injection of excess waters will greatly decrease the costs of energy extraction, decrease energy consumption, and save a potentially valuable water resource for future utilization. |
| Priority | Medium |
| Summary Scope of Work | Develop general approach and decision-making tools to help identify potential injection zones for non-traditional waters produced at energy production sites. |
| Technical Approach | 1. Identify the range of compositions of produced waters in various energy producing regions of the United States<br>2. Identify general properties of receiving zone mineralogy and water chemistry compatible with these injection waters<br>3. Determine methods to rapidly identify potential injection zone meeting compatibility criteria and minimize mixing with adjacent aquifers.<br>4. Identify computational approaches to model biogeochemical changes and their impact on hydrological/geophysical properties of the injection zone.<br>5. Identify existing and emerging technologies for monitoring changing injection zone properties<br>6. Develop decision-making tools to assist site producers and regulators in identifying potential injection zones taking into account evolving regulations<br>7. Conduct field verification of decision-making tools |
| Lead Investigators<br>(academia, natl. lab, industry, international, partnership) | U.S. Geological Survey, industry, academic institutions |
| Potential Collaborative Govt. Agencies | EPA, state governments, DOE |
| Leverage Opportunities with Existing Programs | Unknown |
| Constraints/Challenges<br>(Policy, regulatory, technical, sequencing?) | Current regulations may not be flexible enough |
| Estimated Cost | $1-2M |
| Execution Horizon<br>(early, mid, late) | Early |
| Schedule/Duration | 2 year durations |
| Level of Development/Level of Maturity at completion | Mature product |
| Additional comments | |

| Research Area 4-12e. Reduce fouling of high-concentrate membranes. | |
|---|---|
| Statement of Need | As we move forward to improve water recovery from non-traditional waters, avoiding chemical and bio fouling will become more difficult and will be needed. |
| Research Objective | Assess approaches to reduce fouling of high-concentrate membranes in a cost effective approach while reducing anti-scalant, biofouling chemical needs. |
| Impact/Benefits | Approaches that reduce the need for antiscaling, biofouling chemicals, etc. will significantly reduce operational costs and enable applications in more locations and recover costs. |
| Priority | High |
| Summary Scope of Work | Conduct research and development work to improve process to reduce chemical and biological fouling of concentrate treatment to improve effectiveness. |
| Technical Approach | Research on improved membranes that reduce fouling because of inherent design, especially an issue w/ produced water because organics impact fouling. |
| Lead Investigators (academia, natl. lab, industry, international, partnership) | DOE and national laboratories with industry and universities |
| Potential Collaborative Govt. Agencies | Water associations, AwwaRF and WERF, with oil companies and USBR |
| Leverage Opportunities with Existing Programs | Several research programs are currently underway to look at this, therefore need to collaborate with these programs. |
| Constraints/Challenges (Policy, regulatory, technical, sequencing?) | Use of scale inhibitors and biofouling compounds impact ability to dispose of concentrate. |
| Estimated Cost | $2-3M over 4-5 years. |
| Execution Horizon (early, mid, late) | Mid-early to mid. |
| Schedule/Duration | 4-5 years |
| Level of Development/Level of Maturity at completion | Prototype demonstrations to collect cost and performance data and accelerate applications. |
| Additional comments | |

| Research Area 4-12f. Recycle/reuse membranes. | |
|---|---|
| Statement of Need | A major need in the use of non-traditional water resources is improving the water recovery efficiency. Improving efficiency from the current level of 70-80% to 90-95% would create significant opportunities for use of non-traditional resources. Develop treatment program for RO reject recycling (as an alternative to disposal) to reduce water energy needs. |
| Research Objective | Identify treatment process needs for further concentration of RO reject flows. Develop membrane technology specifically designed to handle concentrate w/ improved water recovery and w/o scaling. |
| Impact/Benefits | In many applications of wastewater disposal, additional treatment of concentrate in an energy- & cost-efficient manner can improve water resource availability and reduce disposal costs. Develop new water to avoid high-energy imported water. Reduce reject disposal requirements and associated costs. |
| Priority | Medium to High. High in areas where insufficient recycled water is available to meet needs. |
| Summary Scope of Work | Develop membranes specifically to handle concentrate streams cost effectively to remove even more water from a waste stream. This includes streams with TDS above 15-20K. Identify RO and pretreatment membranes for reject flows. Conduct applied research (bench testing, pilot testing). Document report(s) and development of program. |
| Technical Approach | Focus concentrate treatment research on techniques, such as new membranes specifically designed for concentrate streams. Identify typical brackish water and wastewater RO reject quality. Test seawater membranes on RO reject feed (dual RO). Specify energy and water savings compared to other options. |
| Lead Investigators<br>(academia, natl. lab, industry, international, partnership) | DOE w/ National Labs. Applied research organizations and departments – water agencies experienced with membranes and recycled water (e.g., Orange County Water District). |
| Potential Collaborative Govt. Agencies | USBR. Has applications w/ water and wastewater industries and their associations… AwwaRF and WERF should be involved. U.S. Salinity Coalition. |
| Leverage Opportunities with Existing Programs | Build on previous testing in El Paso, TX and Middle East. Also, AWWA, WERF, and USBR water reuse, desal, and produced water programs. Tie w/ desal roadmap efforts. |
| Constraints/Challenges<br>(Policy, regulatory, technical, sequencing?) | Technical challenges from high mineral and organic concentration levels and scaling and fouling of process. Regulatory concerns w/ trace contaminant issues in final concentrate. |
| Estimated Cost | Range: $150-250K over 1-2 years to $2M over 4-5 years. |
| Execution Horizon<br>(early, mid, late) | Early to mid-term… 3-to-7 years. Complete applied research within 5-years for follow-on implementation. |
| Schedule/Duration | Begin in FY07 or FY08 for initial effort over 12-18 month duration. 4-5 years to make technology viable. Need to finish desal roadmap before pursuing. |
| Level of Development/Level of Maturity at completion | Demonstration of prototype to collect cost and performance data. Follow-on full scale demonstration probably required to confirm water/energy savings prior to commercial design and implementation. |
| Additional comments | |

| **Research Area 4-12g. Determine the value of marketable by-products that could be extracted from produced waters.** | |
|---|---|
| Statement of Need | A need exists to determine the value of marketable by-products that could be extracted from produced waters; both in terms of their market value and the reduction in concentrate management costs. |
| Research Objective | Two phase: Develop<br>1. Economic model of by-product extraction<br>2. Identify and develop necessary extraction technologies |
| Impact/Benefits | Lower the costs and minimize the environmental impacts of concentrate disposal.<br><br>Avoid energy use and environmental impact of displaced mining activities. |
| Priority | First topic—high priority<br>Second topic—priority set by results of first topic |
| Summary Scope of Work | Compile compositions and amounts of produced waters.<br>Carry out economic analysis of extraction processing.<br>Develop innovative technologies to carry out extractions. |
| Technical Approach | Develop new technologies or new combinations of existing technologies to carry out selective extractions of targeted species from produced waters. This may include advanced membrane technologies such as functionalized selective reverse osmosis or electrodialysis membranes, or new approaches based on computer simulations or innovative materials developed for this purpose. Some produced waters contain components such as ammonia that can be converted to energy as hydrogen or electricity. These mineral and energy extraction efforts should be guided by computer modeling of concentrated salt solutions and of membrane transport processes. |
| Lead Investigators<br>(academia, natl. lab, industry, international, partnership) | Combination of national labs (lead), academia (modeling), industry (field testing). Asahi (Japan) is leading technology provider for electrodialysis used to process brines. |
| Potential Collaborative Govt. Agencies | USGS—database of produced waters<br>State agencies—regulate fossil fuel production |
| Leverage Opportunities with Existing Programs | DOE Geothermal—mineral extraction from geothermal fluid<br>DOE Industrial Technologies—industrial separations<br>Yucca Mtn Project—thermodynamics of brines |
| Constraints/Challenges<br>(Policy, regulatory, technical, sequencing?) | Low value of most mineral by-products necessitates a low cost separation technology; must process high salinity and therefore corrosive waters; by-products may contain regulated toxic species |
| Estimated Cost | Phase 1 (Economic analysis), $1M<br>Phase 2 (technology development), $2-5M/project |
| Execution Horizon<br>(early, mid, late) | Phase 1 (Economic analysis), early (1-2 years)<br>Phase 2 (technology development), mid to late |
| Schedule/Duration | Phase 1 (Economic analysis), 1-2 years<br>Phase 2 (technology development), 3-6 years |
| Level of Development/Level of Maturity at completion | Technologies developed through pilot testing phase at field sites |
| Additional comments | Notes: Salts—gypsum, ppt. calcium carbonate, Br, I, Li, Mg-salts, B, NH(3), Se, halite produce hydrogen from ammonia |

| Research Area 4-12h. Membrane process reject recycling. | |
|---|---|
| Statement of Need | Develop treatment program for RO reject recycling (rather than disposal) to reduce water energy needs. |
| Research Objective | Identify treatment process needs for further concentration of RO reject flows. |
| Impact/Benefits | 1. Develop new water to avoid use of high-energy imported water<br>2. Reduce reject disposal requirements |
| Priority | Medium; high in areas where insufficient recycled water is available to meet needs. |
| Summary Scope of Work | 1. Identify RO and pretreatment membranes for reject flows.<br>2. Conduct applied research (bench tasting, pilot testing)<br>3. Documentation report and development program. |
| Technical Approach | 1. Identify typical brackish water and wastewater RO reject quality<br>2. Test seawater membranes on RO reject feed (dual RO)<br>3. Specify water and energy savings compared to other options. |
| Lead Investigators (academia, natl. lab, industry, international, partnership) | Applied research departments—water agencies experienced with membranes/recycled water (e.g., Orange County Water District) |
| Potential Collaborative Govt. Agencies | US Salinity Coalition |
| Leverage Opportunities with Existing Programs | Build on previous testing in El Paso, TX, Middle East |
| Constraints/Challenges (Policy, regulatory, technical, sequencing?) | Technical treatability challenges from high mineral and organic levels |
| Estimated Cost | $150-250k |
| Execution Horizon (early, mid, late) | Early (complete applied research within five years for follow-on implementation) |
| Schedule/Duration | Start in FY07 or FY08<br>Approximate 12-18 month duration |
| Level of Development/Level of Maturity at completion | Follow on full-scale demonstration probably required to confirm water/energy savings prior to design and implementation. |
| Additional comments | |

| **Research Area 4-13. Conduct research on membranes for use with waste heat desalination processes for upgrading non-traditional waters.** | |
|---|---|
| Statement of Need | Massive volumes of low-grade heat are currently wasted in industry. We need a low-cost, membrane/waste heat driven desalination process that will allow low quality water resources to be utilized where they are located. |
| Research Objective | Combine membrane and waste-heat into technologies to treat impaired water. |
| Impact/Benefits | Reduce consumption of fresh water through treatment and use of impaired water. Create new water source from impaired water. |
| Priority | High |
| Summary Scope of Work | Develop and evaluate cost-effective technologies for upgrading non-traditional water that integrate waste heat with water treatment processes (membrane, dewvaporation, etc.) |
| Technical Approach | • Investigate low-temperature desalination processes that involve phase change<br>○ Evaluate direct-contact membrane distillation within temperature range of interest.<br>○ Dewvaporation<br>○ Demonstrate impact of fouling due to inorganics, organics, and organisms.<br>• Evaluate effect of temperature increase (~20ºF) on conventional reverse-osmosis (or nanofiltration) membrane or electro-dialysis-reversal performance. Use this as a baseline for comparison with other technologies.<br>• Match technologies to intended water-quality goals (e.g., RO at high temperature would have lower rejection, but this could be adequate for cooling water). |
| Lead Investigators (academia, natl. lab, industry, international, partnership) | National laboratories, academia |
| Potential Collaborative Govt. Agencies | DOE, USBR (desalination), USGS (decontamination), EPA |
| Leverage Opportunities with Existing Programs | Partnering with industries that produce waste heat near non-traditional water supplies. Existing water research institutions may have similar programs (EPRI, AwwaRF). |
| Constraints/Challenges (Policy, regulatory, technical, sequencing?) | Discharged cooling water is typically only ~20 ºF higher than the incoming water. Therefore, the technology of membrane distillation may be most suited for concentrate stream. These treatment processes will still yield residual that need to be managed per regulatory requirements. |
| Estimated Cost | R&D: $5M over 5 years<br>Demonstration: $10M per technology over 5 years |
| Execution Horizon (early, mid, late) | R&D: Early<br>Demonstration: Mid |
| Schedule/Duration | 10 years total |
| Level of Development/Level of Maturity at completion | Ready for commercial deployment after 10 years. |
| Additional comments | |

| **Research Area 4-15. Cycles of concentration-characterization of waters, new treatment technologies to increase number of cooling cycles and reuse of scrubber water.**<br><br>**NB. Also covers Research Area 4-14. Polishing systems to combat water-quality problems with scrubber water re-use.** | |
|---|---|
| Statement of Need | Closed-loop cooling systems are based on extensive cycling of water; the number of cycles-before-disposal needs to be increased to reduce fresh water withdrawals. |
| Research Objective | Reduce water consumption and increase power-generation reliability through high-efficiency, cost-effective, closed-loop cooling (at least twice the number of current cycles) and reuse of process waters (e.g., scrubber water) |
| Impact/Benefits | Decreased water consumption, decreased disposal of impaired water, reduced dependence on cyclical loads (shaving peaks), increased reliability of power generation, and environmental stewardship of water. |
| Priority | High |
| Summary Scope of Work | Develop methods, materials, and identify technologies that would enable the implementation of high-efficiency, cost-effective, closed-loop cooling. |
| Technical Approach | • Need to develop model that will guide process design and optimization for use and implementation of water cycling that is integrated with treatment.<br>• Identify and develop appropriate materials for entire cooling cycles (condenser, heat exchanger, etc.) with low propensity to scaling, fouling, and corrosion that lend themselves to use of impaired waters and increased cycles of concentration.<br>• Develop concentrate management strategies that include biodegradable anti-scalants, beneficial re-use applications, characterization of discharge for compliance with regulatory requirements (includes cooling tower drift), further treatment such as membrane bio-reactors (residual digestion), recovering energy resources from biodegradation (e.g., methane)<br>• Develop new treatment technologies and/or methods for increasing cycles of concentration as needed<br>    ○ Consider process integration with cooling system<br>    ○ Energy recovery devices (for cooling when using seawater)<br>    ○ Evaluate appropriateness of treatment technologies (e.g., how membranes perform at different temperatures)<br>    ○ Evaluate potential for concentrate recycling to beginning of cooling or scrubber cycle for dilution.<br>• Develop polishing systems to mitigate water-quality problems associated with scrubber water reuse<br>    ○ High-recovery reverse osmosis with precipitative techniques (95% recovery)<br>    ○ Direct-contact membrane distillation |
| Lead Investigators (academia, natl. lab, industry, international, partnership) | DOE national laboratories, academia, research institutions, Gas Technology Institute, NALCO |
| Potential Collaborative Govt. Agencies | DOE, EPA |
| Leverage Opportunities with Existing Programs | Power utilities. |
| Constraints/Challenges (Policy, regulatory, technical, sequencing?) | Increased cycles will increase the concentrate and its potential toxicity. How do you dispose of this? |
| Estimated Cost | R&D: $3M/year over 10 years |

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|---|---|
| | Demonstration:  $10M per project over 5 years |
| Execution Horizon<br>(early, mid, late) | R&D:  Early<br>Demo:  Mid |
| Schedule/Duration | R&D:  10 years<br>Demonstration:  5 years |
| Level of Development/Level of Maturity at completion | Ready for commercial deployment |
| Additional comments | |

| Research Area 4-16. Predictable, stable, science-based regulatory environment for produced water discharge. | |
|---|---|
| Statement of Need | Develop a predictable, stable regulatory environment that is science based and adheres to a standard regulations development process to establish permit requirements. |
| Research Objective | Establish a standing technical review committee that will evaluate proposed institutional requirements (policies, regulations, standards, regulatory and permits) to provide a peer reviewed science based validation. Socio-economic analyses will be an essential part of these assessments. |
| Impact/Benefits | Provide a predictable environment of permit requirements enabling industry to plan long term development. |
| Priority | Highest |
| Summary Scope of Work | Establish a technical committee of scientists, policy analysts and engineers, knowledgeable of energy / water development and institutional requirements affecting them on State and Federal levels. Additionally, socio-economic analyses are essential. |
| Technical Approach | Provide quick turnaround review and analysis of developing and proposed changes to institutional requirements, and to provide “expert” testimony as necessary. |
| Lead Investigators (academia, natl. lab, industry, international, partnership) | National laboratories |
| Potential Collaborative Govt. Agencies | |
| Leverage Opportunities with Existing Programs | All applicable sources of peer reviewed literature and professional expertise. |
| Constraints/Challenges (Policy, regulatory, technical, sequencing?) | Funding available. |
| Estimated Cost | |
| Execution Horizon (early, mid, late) | Early |
| Schedule/Duration | Ongoing |
| Level of Development/Level of Maturity at completion | Mature from the onset. |
| Additional comments | |